U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

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INTEGRATED MESOSCALE URBAN SYSTEMS MODELING WITH BEHAVIOR, ENERGY, AUTONOMY, AND MOBILITY MODEL

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Argonne NATIONAL LABORATORY · BERKELEY LAB · Idaho National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY · OAK RIDGE National Laboratory

OVERVIEW

Timeline

- Start date: 10/2016
- End date: 3/2020
- Percent complete: 100%

Budget

- Total funding: $2.5 M
  - DOE share: 100%
- FY 2017: $0.5M
- FY 2018: $0.5M
- FY 2019: $1.1M
- FY 2020: $0.4M

Barriers

- Limited understanding of system-impacts of major mobility trends (electrification, automation, sharing)
- Scalable modeling of integrated future transportation system is difficult

Partners

- Project Lead: LBNL
- Partners: NREL, ORNL, INL, ANL

RELEVANCE

Behavioral Simulation of Transportation Systems

What is the goal?

- "…***generate knowledge*** that industry can advance to deploy innovative energy technologies to support ***affordable, secure, reliable, and efficient transportation systems*** across America."
- "***Identify pathways*** and develop innovative technologies and systems that can dramatically ***improve mobility energy productivity*** when adopted at scale."

- 2019 Annual Merit Review: Energy Efficient Mobility Systems, Vehicle Technologies Office

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RELEVANCE

Behavioral Simulation of Transportation Systems

What is the problem?

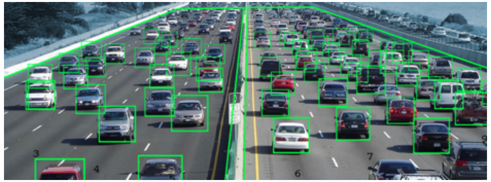
- Automation, electrification, and other changes will transform transportation systems in unknown ways
- Behavioral change will be just as important as technology change in shaping the future transportation landscape--how do they interact?

What is needed?

- Tools for federal and local decision makers
- Better understand the scope, bounds, and interactions influencing systemwide travel and energy use
- Scenario analysis, not a prediction

RELEVANCE: MODEL SCOPE

New Forms of Mobility



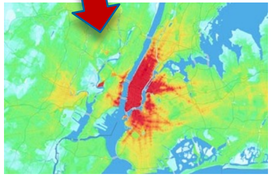
Enhanced Traffic Flow

Vehicle Ownership /
Vehicle Energy Performance

Traveler Behavior

Land Use Change

Charging Siting & Operations



Mobility Energy Productivity

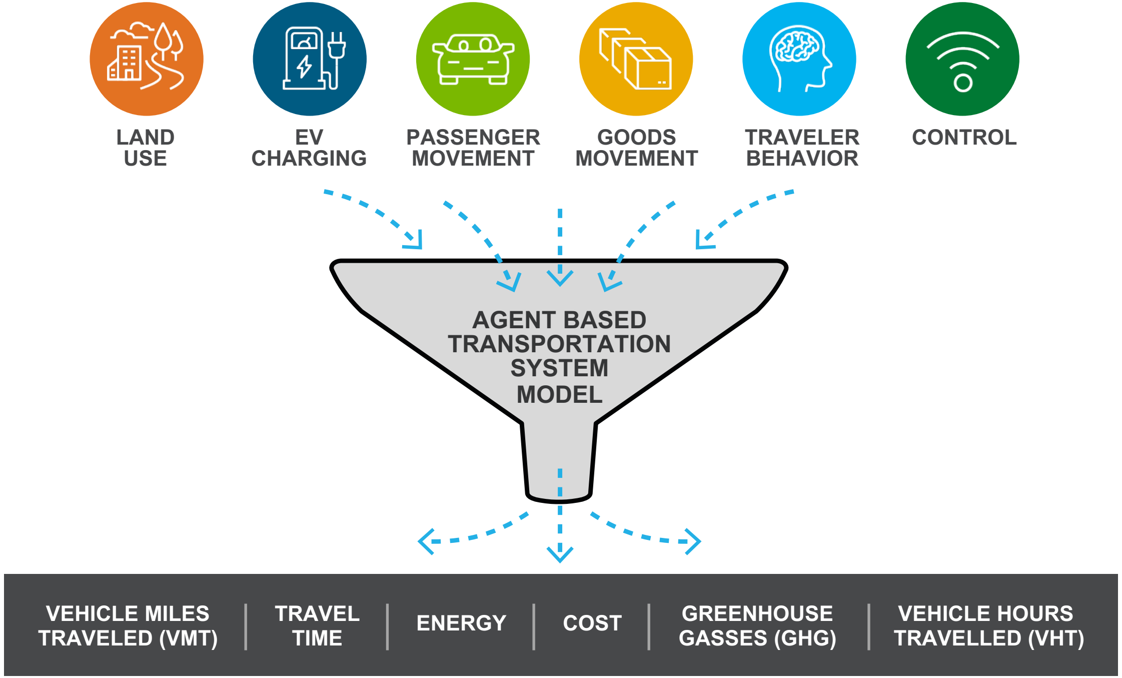
MILESTONES

Deadline	Milestone	Status
March 2019	Added all needed components to BEAM and completed all needed integrations with other models in SMART consortium to allow for SMART Workflow analysis. Preliminary Implementation of Workflow Taskforce model scenarios	Complete
June 2019	Completion of Workflow scenario analysis	Complete
Sept 2019	Final results included in SMART Capstone Reports	Complete
March 2020	SMART Capstone Reports complete	Complete

APPROACH

SMART Mobility Modeling Workflow

By creating a multi-fidelity end-to-end modeling workflow, SMART Mobility researchers advanced the state-of-the-art in transportation system modeling and simulation



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MODELING ACROSS TIME SCALES

Scenario generation

Long term
- Land use
- Charging infrastructure
- Vehicle fleet

Day to day
- Mode choice
- Fleet behavior
- Traffic patterns

Second by second
- Energy use
- Vehicle interactions

Scenario evaluation

MODELING ACROSS TIME SCALES

Whole Traveler / POLARIS coordination

Long term	Day to day	Second by second
UrbanSim	BEAM	Route-E / FastSim
EVI-Pro, FCSPlan		AIMSUN
ADOPT		

MEP

WORKFLOW ABM COMPARISONS

Inputs:

Light duty fleet powertrain / automation mix	Scenario input
Personal vehicle retirement rate	Scenario input
Individual household vehicle ownership	Endogenous
Value of time factors	Scenario input
Home and work locations	Endogenous
Ride-hail fleet size	Calibrated

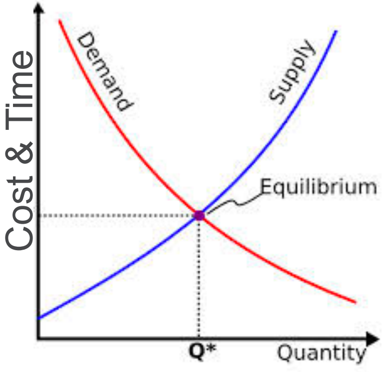
Model features:

	BEAM	POLARIS
Land use change	External	External
Goods movement	Pending	Included
Discretionary activities	Included*	Included
Pooled ride-hail	Included	Included
Ride-hail repositioning / charging	Included	Included*
Population size	Sampled	Full

BEAM RESOURCE MARKETS

- Road Capacity
- Vehicle Capacity
- Ride Hail Availability
- Parking/Refueling Access

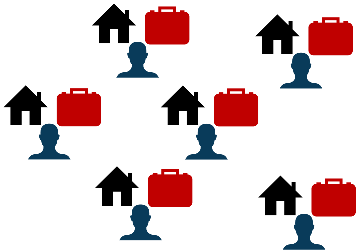
- Supply:
  - Ride Hail
  - Vehicle sharing
  - Driving
  - Transit
  - Parking
  - Charging Infrastructure
  - Biking, Walking



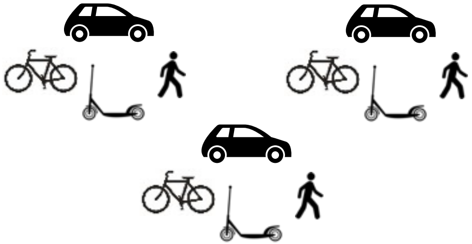
- Demand (governed by behaviors):
  - Mode Choice
  - Route Choice
  - Rerouting
  - Park Choice
  - Refuel Choice

LAND USE EVOLUTION

UrbanSim



BEAM



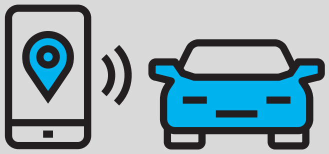
- UrbanSim evolves land-use in metro-areas
- Firms choose where to locate
- Households choose where to live
- Persons choose where to work
- Synthesizes activity chains now used in BEAM

ACCOMPLISHMENTS SUMMARY

- Developed state-of-the-art agent-based transportation demand model
  - Using actor method designed for highly parallel HPC architectures
  - Including dynamic matching of solo and pooled ride-hailing, household automated vehicle scheduling and sharing, charging needs for personal vehicles and shared fleets
  - Linked to other SMART Mobility Consortium tools defining land use change, charging infrastructure siting, vehicle energy use, and MEP calculations
  - Recent updates to ride hail pooling and repositioning, parking and charging choice, and UrbanSim software integration
- Defined and coded future mobility scenarios spanning disparate potential mobility futures
- Ran long-term simulations of these scenarios
- Generated insights based on these and additional runs

SCENARIOS

HIGH SHARING, PARTIAL AUTOMATION (A)



Medium-Term Future

A2 - Business-as-usual vehicles
A3 - DOE vehicle technology success

HIGH SHARING, HIGH AUTOMATION (B)

Long-Term Future

B5 - Business-as-usual vehicles
B6 - DOE vehicle technology success

LOW SHARING, HIGH AUTOMATION (C)

Long-Term Future

C5 - Business-as-usual vehicles
C6 - DOE vehicle technology success

BASELINES

Base0 – Present Day

Base2 – **Medium-Term**, BAU Vehicles
Base3 – **Medium-Term**, Tech Success

Base5 – **Long-Term Future**, BAU Vehicles
Base6 – **Long-Term Future**, Tech Success

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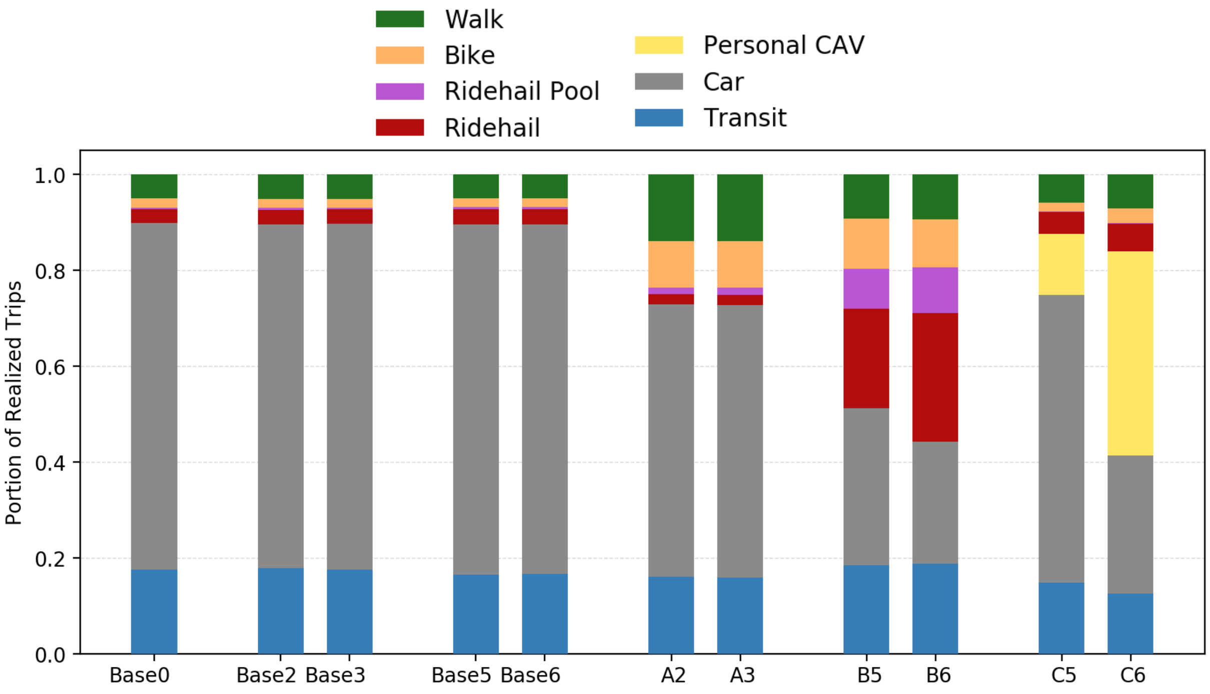
MODAL SPLITS

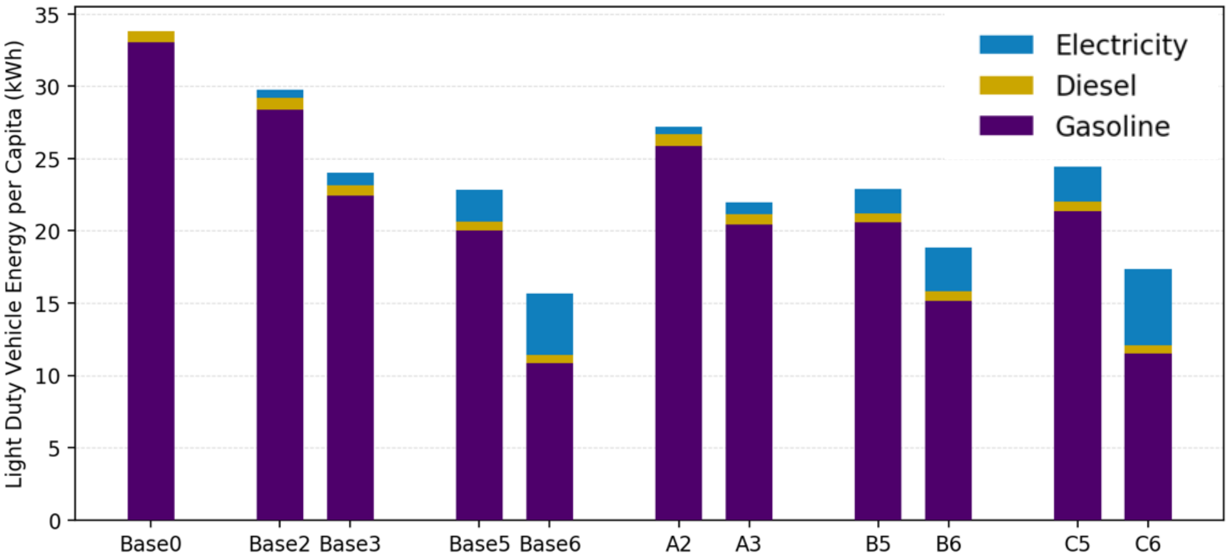
Household vehicle ownership assumptions and different valuations of travel time are main drivers of variation in commuting mode share across scenarios; changes to both are required to replace private car travel



Modal Market Shares for commute in San Francisco Bay Area across Scenarios

LIGHT DUTY VEHICLE ENERGY

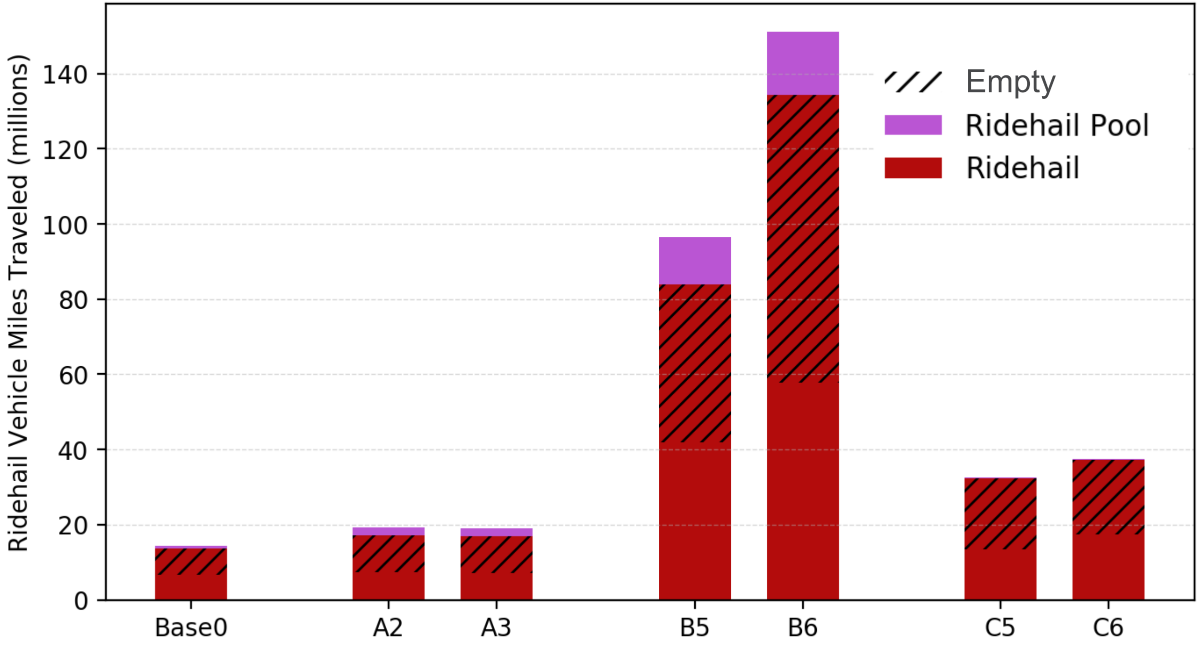
Advanced powertrain technologies, including electrification, remain the primary factor influencing future transportation energy use, having a greater impact than either vehicle sharing or automation



Per capita light duty vehicle energy consumption by fuel type for the San Francisco Bay Area

RIDE HAIL VMT

Increasing ride hail occupancy while maintaining high enough quality service to attract travelers is a fundamentally difficult problem.

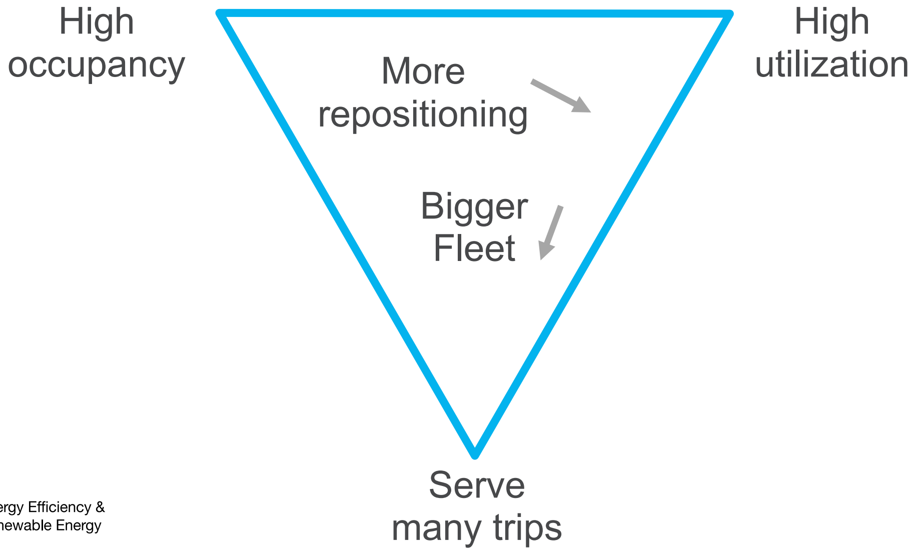


Vehicle miles traveled by ride hail for the San Francisco Bay Area, differentiating between empty vehicle (hatched) and multiple passengers (purple) miles

RIDE HAIL SENSITIVITY ANALYSIS

Assumptions about ride hail fleet operations are very important

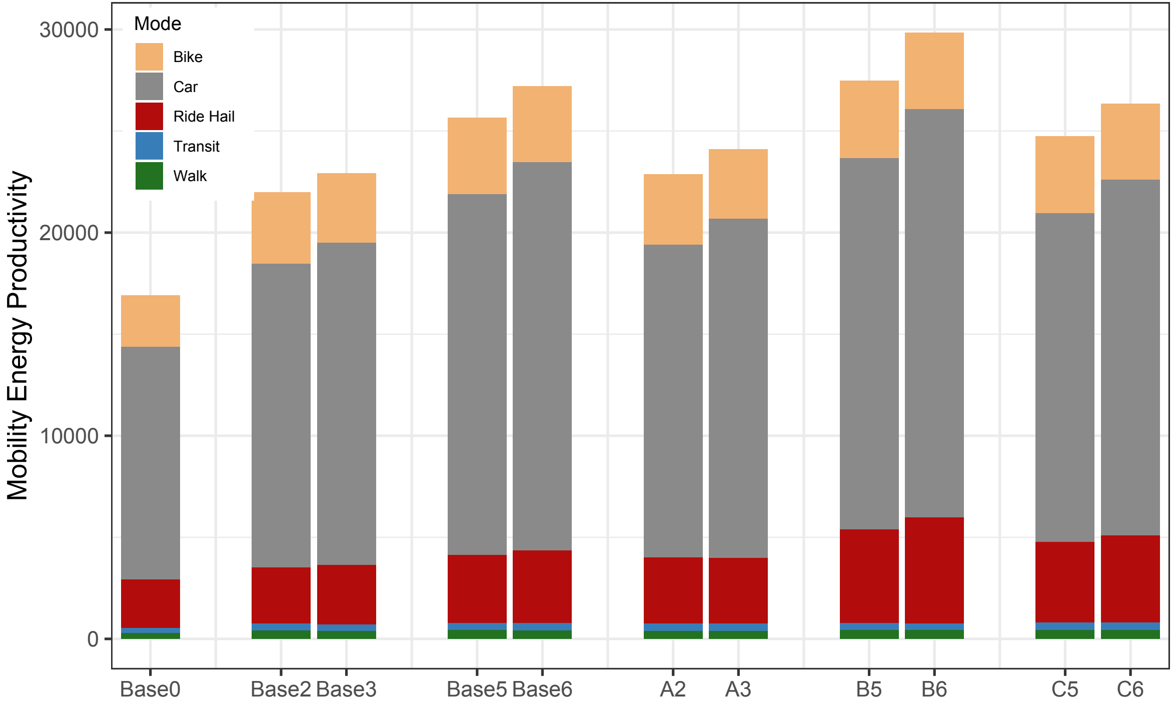
Elasticity of / WRT	Wait Time	VMT	Occupancy	Total Trips	Rides / Vehicle
Fleet Size	-0.14	0.48	-0.35	0.28	-0.72
Repositioning	-0.04	0.22	-0.22	0.002	0.002



- Empty VMT from ride hailing drove major differences between scenarios
- Assumptions about fleet size and repositioning are important
- Reveals important trade-offs in fleet management

MOBILITY ENERGY PRODUCTIVITY

MEP scores are higher than baseline for shared mobility scenarios (A&B), but are lower for the privately owned automobile scenario (C); suggests that shared mobility can augment vehicle technology improvement



SF Bay Area MEP values across the workflow scenarios

RESPONSES TO REVIEWERS

Sensitivity analysis

- *"… more important to the EEMS mission to* ***establish confidence bounds around the results*** *using the current version of the model before expending more resources to perfect the model.* ***Monte Carlo simulations by varying key input variable values*** *can be very informative exercise, and it is especially critical for the value of time variable because that is the essence of the behavioral refinement in BEAM"*
  - This is very important, and some progress has been made, especially focusing on ride-hailing fleet
  - Simulation speed essential to allow full exploration of input parameter space and sensitivity

RESPONSES TO REVIEWERS

Comparability with POLARIS

- *"There appears to be significant overlap with Argonne National Laboratory (ANL) tools and process work…, especially with respect to POLARIS. It seems that better coordination here would help and be more effective."*
    - Consistency in scenario assumptions critical in ensemble modeling
    - Ongoing work to apply both models to the same cities
    - Growing overlap between model features will improve comparisons

Real world application / validation / calibration

- *"more emphasis could be placed on validation of the complete system simulation."*
    - Process is ongoing, aided by new cities and tighter UrbanSim coupling
    - Developing promising relationships developing with mobility providers (transit, TNC) to validate internal model consistency

COLLABORATION AND COORDINATION

Core model development collaborators

NREL	Vehicle fleet and energy use, charging locations, MEP, Charging/parking behavior
UC Berkeley	Land use, CAV traffic flow impacts, charging infrastructure
INL	Charging infrastructure
ANL	Scenario design

COLLABORATION AND COORDINATION

Additional developers, users, and collaborators

SFMTA, BART	Transit data
Uber, Cabify	Ride hail data, fleet planning
EVGo	Charging data
Marain	Electric/automated fleet operations
EPA, CEC	Scenario analysis and planning, electrification
SJSU, TU-Munich	Automated shuttles, ride hail planning
UCR, TU-Dortmund	Freight electrification, parking/charging choice

REMAINING CHALLENGES

- **Improving runtime**
  - A full metro-area sized run of BEAM takes 12-24 hours. This is fine for analyzing 10s of scenarios, more challenging for 100s or 1,000s
- **More endogeneity in scenario inputs**
  - Certain factors (personal vehicle retirement, ride hail fleet size and automation levels, infrastructure availability) were treated as fixed scenario inputs, but they are unknowns that could be modeled endogenously
- **Balancing behavioral realism and validation**
  - Validation is difficult when considering massive and fundamental transformations of the transportation system
  - Backcasting is difficult when so many factors are changing at once

PROPOSED FUTURE RESEARCH

- **Improving runtime**
  - Focus on computational efficiency, more parallelism, and faster convergence
  - Reduce memory overhead, take full advantage of asynchronous actor model
  - Create reduced-form version of the model for quick scenario analysis
- **More endogeneity in scenario inputs**
  - Tighter coupling with other behavioral models, including more data exchange and more consistency in simulated agents
  - Incorporating life cycle stages into home/work location and value of time
  - Endogenous pricing and fleet sizing behavior for mobility providers
- **Balancing behavioral realism and validation**
  - More detailed handling of non-work travel behavior
  - More detail and validation of model components (transit, parking, ride-hailing)
  - Automatic whole-model validation with back-casting and sensitivity analysis

PROJECT SUMMARY

- Developed state-of-the-art agent based transportation demand model and ran it on future mobility scenarios spanning disparate potential mobility futures, finding:
  - Advanced vehicle technologies are the primary factor influencing future transportation energy consumption, having a greater impact than either vehicle sharing or automation
  - MEP results are strongly tied to vehicle energy efficiency and roadway speeds
  - While pooling (increasing occupancy of light-duty vehicles) is normally expected to enable a more efficient future transportation system, scenarios focused on pooling perform no better than those with baseline behavior and the same powertrains
  - There is an inherent conflict between fleet utilization, service quality, and empty vehicle movement. Increasing ride-hail occupancy while maintaining high enough quality service to attract travelers is a fundamentally difficult problem

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MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION

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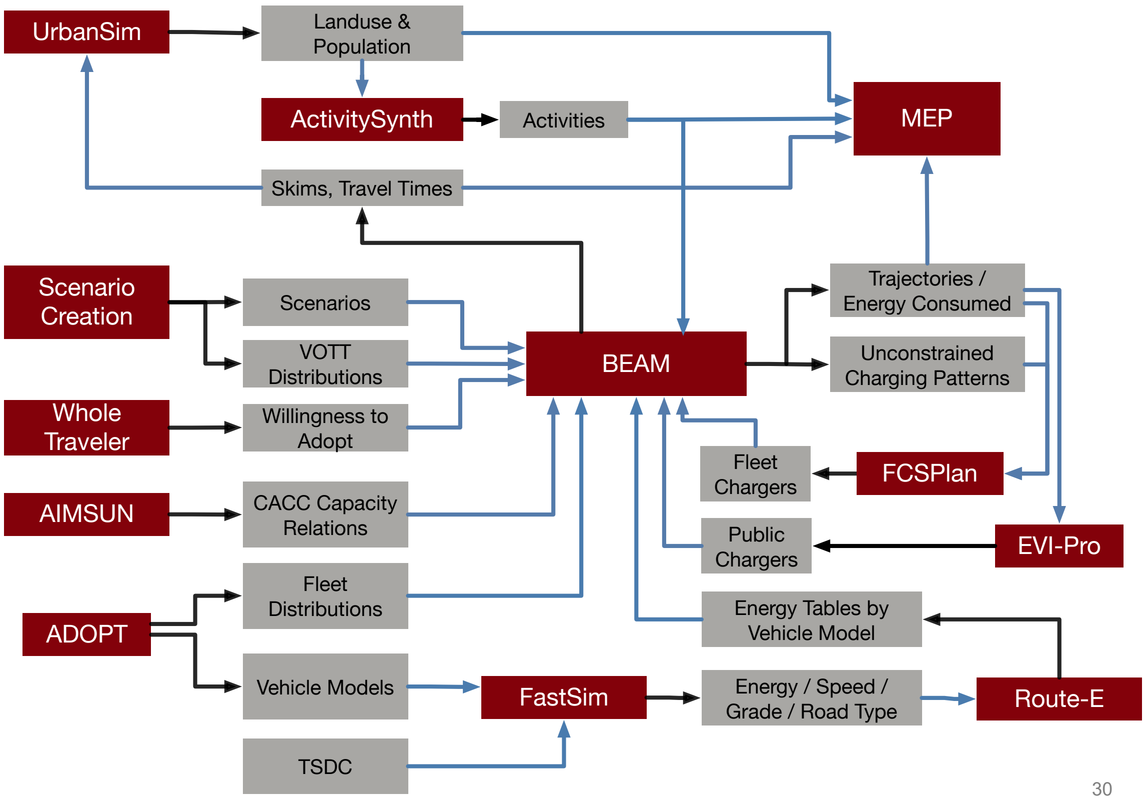
Technical Backup Slides

SF BAY AREA WORKFLOW IMPLEMENTATION

Key Team:

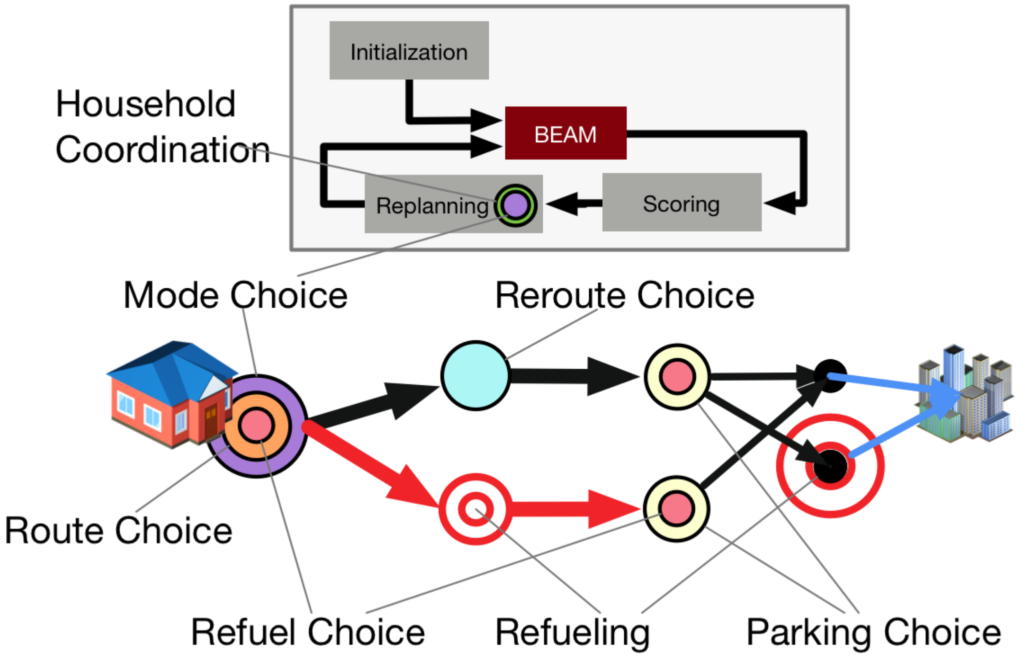
- LBNL
- NREL
- UC Berkeley



BEHAVIORAL MODELING IN BEAM

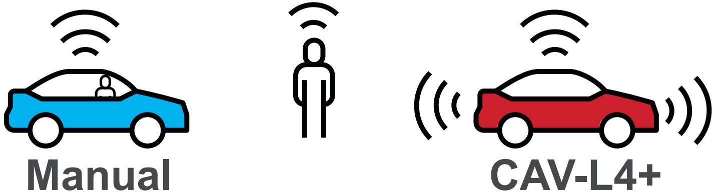
Hybrid of before-day and within-day planning.

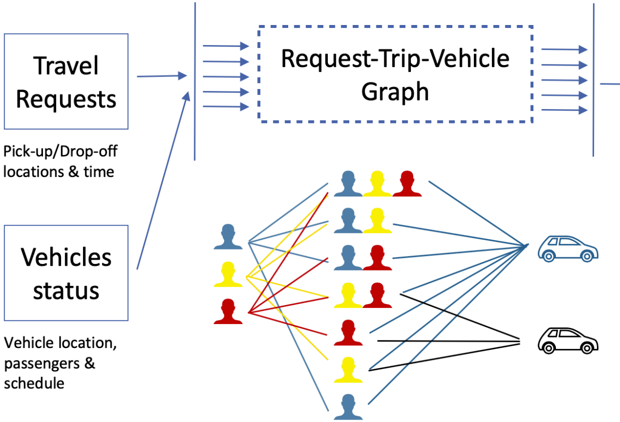
Mode, trip, and route planning dynamic (on-the-fly)… enabling faster convergence toward user equilibrium.

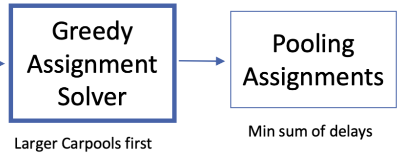


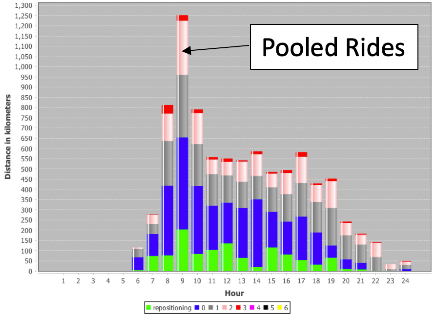
RIDE HAIL OPERATIONS

- ***Manual / AV Hybrid Fleet***
- ***Dynamic allocation of vehicles to customers.***
- ***Assignment executed every 90 seconds.***
- ***Real-time price and wait time quotes***
- ***API allowing flexible extensions***









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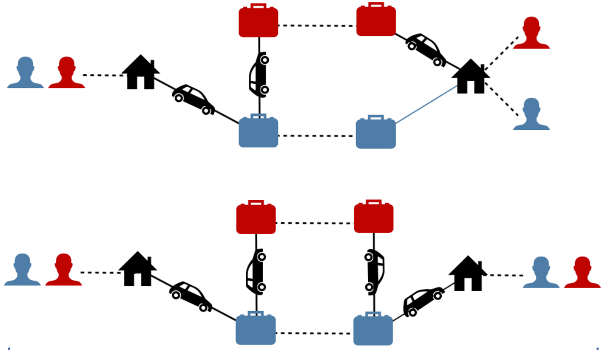
PRIVATELY OWNED CAVS

- ***Households coordinate to deploy L4+ CAVs to best serve mobility of all members***
- ***Tours that cannot be accommodated go through regular mode choice process***

Household Travel Requests

Household Trips & Chain-based Tours

Household Fleet of CAVs



Whole Day Combinatorial Assignment

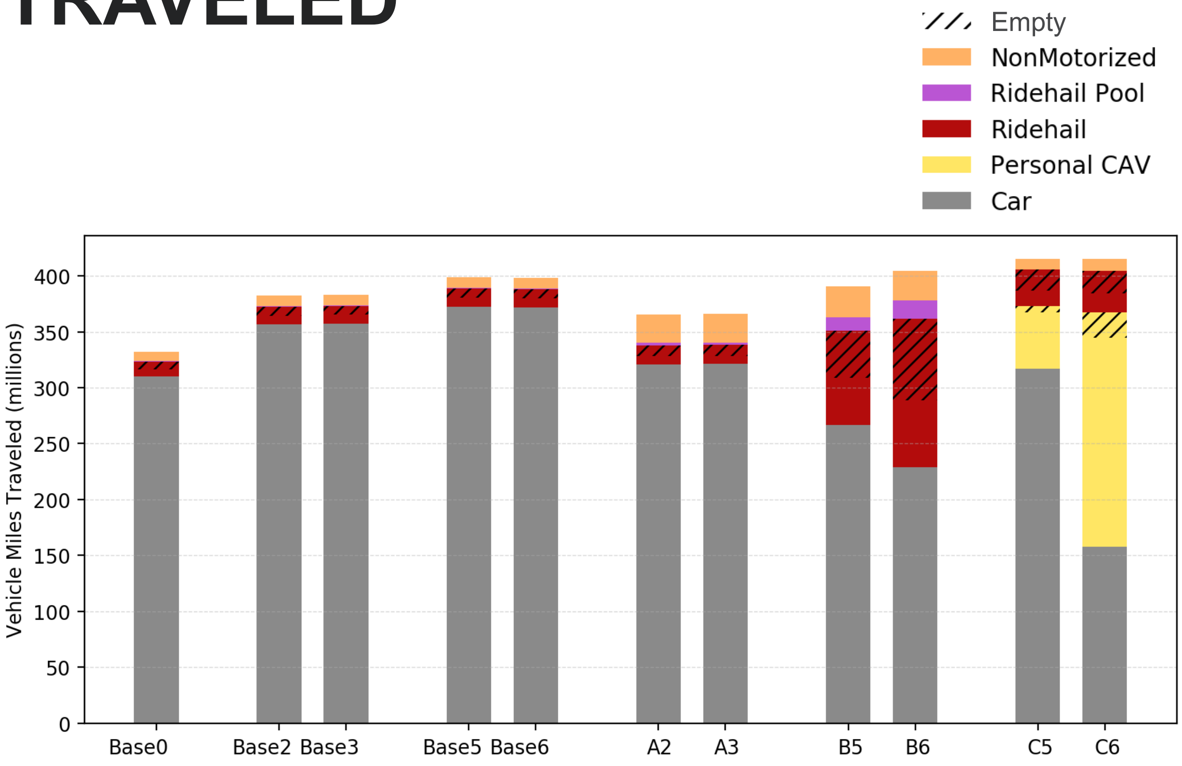
(First to ask is the first to be served)

Scoring + CAV Assignments

(Household sum of travel times)

VEHICLE MILES TRAVELED

Neither preference for walking, biking, and shared modes (Scenario A) nor moderate personal vehicle retirement rates (Scenario C) replace personal car travel as majority commute mode (including transit which is not shown here)



Total vehicle miles traveled for commuting by mode for the San Francisco Bay Area.